Pattern analyses on the vocal structure of calls and geographic variations among three areas

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ABSTRACT
Dugongs (*Dugong dugon*) vocalize several calls in a row. Previous reports showed that dugongs have two kinds of calls: long duration calls (trills) and short duration calls (chirp-squeaks hereinafter called chirps). Vocalization pattern of the dugong were classified and the differences and the similarities in the phonetic structure among different dugong populations are discussed in this paper. We recorded the dugong calls from the southern part of Talibong Island, Thailand (2222 calls in total), Toba aquarium, Japan (694 calls), and Underwater World, Singapore (203 calls). Short duration calls with less than 300 milliseconds were defined as chirps and trills ware defined as a call lasting over 300 milliseconds. The end of a call sequence was defined by a silence over 1 second. Within a call sequence, chirp-to-chirp transition was the most frequent among the 3 groups. Trills appeared at the end of a call sequence. The position of the trill did not differ among the 3 groups. The average of the dominant frequency component of dugong calls collected in Thai waters was 4179.8 $\pm$ 1630.6 Hz (S.D.), 2567.2 $\pm$ 1371.3 Hz (S.D.) in Toba aquarium, and 7362 $\pm$ 1745.6 Hz (S.D.) in Underwater world. This study provided detailed information on the vocalization pattern of the dugong, although the functional use of the calls in the context of acoustic communication is yet to be clarified.

KEYWORDS: ***Dugong dugon*, chirp, trill, call sequence, vocalization pattern**

INTRODUCTION

The Dugong (*Dugong dugon*) is sea mammal. They live in tropical or subtropical shallow waters that overlap human activity areas such as coastal fishing zones. It is said that confliction between humans and dugongs is one of the causes of the decreasing dugong population. Dugong are listed as vulnerable to extinction in IUCN red list. All populations are in Appendix Ⅰ except the Australian populations, which are in Appendix Ⅱ in the Convention on International Trade in Endangered Species CITES. However, it has been difficult to protect them because their behavioral information was too limited. It is therefore important that we obtain information on how the dugongs live. If we know such information and develop effective control, we should be able to maximize the effectiveness of dugong protection, as well as to minimize the hindrance to human activity.

Generally, vocalization patterns have important meanings in animal behavior. Ford (1989) suggested that discrete calls of killer whales (*Orcinus orca*) are used to maintain contact between group members and serve as indicators of group affiliation. The term *song* is used in animals, such as songbirds (Okanoya, 2003) and whales (D'Vincent *et al*., 1985), to describe an acoustic signal that involves a wide variety of sounds repeated in a specific sequence. A pattern analysis of animal vocalization provides us with important information on the animal communication. From these investigations, we can estimate the position of the animals, the time when they are present, and the group size.

Dugongs are known to vocalize bird-like calls. They vocalize several calls in a row (Ichikawa *et al*., 2004) (Fig.1). Previous reports gave valuable basic information on dugong calls (Anderson, 1995), but there had been no detailed quantitative characterization of dugong calls. In addition, the vocalization pattern of the calls, have never been studied.

OBJECTIVES

Characteristics of acoustic vocalizations are affected by the acoustic environments among habitats(Sugiura, 1999). The objectives of this study were to find and

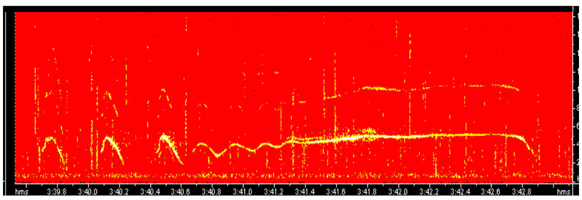

Fig. 1 Sonograms of dugong calls. There are 4 calls in total.

define sequential structures of dugong vocalizations within local populations. To do this, the vocalizations of dugongs were decomposed and the vocalization patterns were classified. Then, the geographic variations of dugong vocalization pattern among different dugong populations were examined.

MATERIALS AND METHODS

Figure 2 shows the data collection sites. Data sets were collected from Thailand, the Toba aquarium, and Underwater World Singapore.

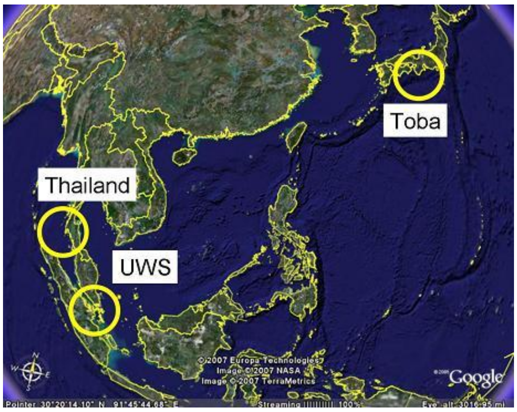

Fig.2 Data-collection areas. Dugong vocalizations were collected from Thailand, the Toba aquarium (Japan), and Underwater World Singapore (UWS: Singapore).

Data acquisition from wild dugongs

The underwater sound data was recorded by an Automatic Underwater SOund Monitoring System for Dugong (AUSOMS-D) in the southern part of Talibong Island, Trang, Thailand (longitude: N07°13.970' latitude: E99°26.799', Fig.3). AUSOMS-D is a stereophonic recording device that consists of a set of hydrophones which are set 2 m apart from each other and a pressure tight chassis. The dugong calls were recorded with CD quality. The AUSOMS-D records the underwater sound with a set of stereo hydrophones at 44.1 kHz sampling rate for over 110 hours (Ichikawa *et al.* 2004-b). The recording took place from 29th February, to 4th March 2004. We analyzed 15 hours of recorded dugong calls.

Data acquisition from captive dugongs in the Toba aquarium

There are two dugongs in Toba aquarium in Japan (longitude: N034°29'12.63" latitude: E136°50'35.46). Individual A is a male dugong. It was found stranded and captured in 1978 in Philippines. It was then brought to Toba aquarium in Japan in 1979 and has been kept since then. Individual B is a female dugong. It was also found in 1986 in Philippines and has been kept in Toba aquarium since 1987. Data of Individuals A and B was stored on digital audio tape (DAT).

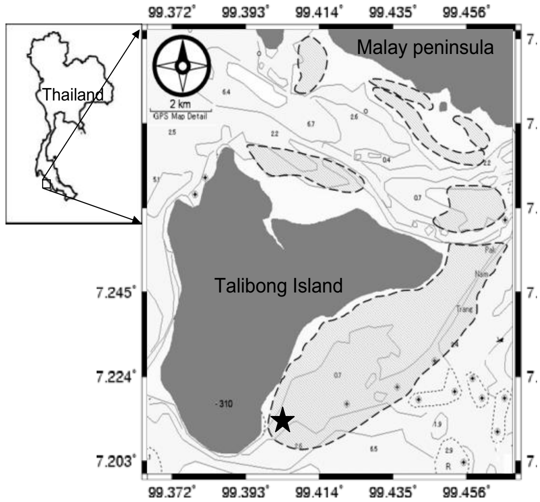

Fig. 3 Research site around Talibong Island, Trang

Data acquisition from captive dugongs in Underwater World Singapore

There is a captive dugong in Underwater World Singapore (longitude: N01°14'59.85" latitude: E103°50'02.09"). Individual C is a female dugong. She was found entwined to the fishing tool and captured with her mother in 1998 in Singapore territory. Her mother had already been dead. She was about six months old and unweaned. She has been kept in the Underwater World Singapore since 1998.

Captive dugong calls were recorded using underwater sound recorder, Aquafeeler developed by System Intech Co., Ltd. of Tokyo, Japan. Aquafeeler is electrically powered by dry-cell batteries. The hydrophones (sensitivity: −190 dB re 1V/μPa) were set 1 m deep. The recording range was 120 dB, and 1 kHz high pass filter was applied. Data of an individual in UWS was stored on hard disk (SONY PCM-D1).

Definition of "call sequence"

Dugongs usually vocalize plural calls successively.

In this study, we defined "a call sequence" as "a group of calls with intervals less than 1 second." We classified calls into two groups: chirps and trills. We defined Chirps as calls with a duration of less than 300 ms., and Trills as calls with a duration of over 300 ms. For example, in Fig.1, there are 3 chirps and 1 trill, and if all the intervals of these calls are less than 1 sec, they are included in the same call sequence.

Structure of call sequence

The position of trills within a call sequence was examined. First, we identified each call unit with serial numbers in the sequence. Second, the order and trill was calculated.

Each call was assigned a call number in a call sequence. Then the order of trills was divided by

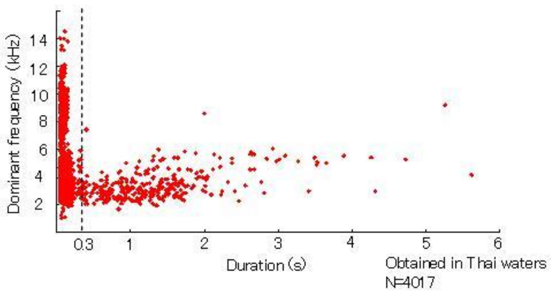

Fig. 4 Duration vs. dominant frequency of dugong calls. The horizontal axis is the duration (s), the vertical axis is dominant frequency (kHz).

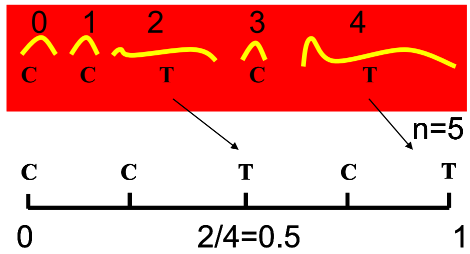

Fig. 6 Order of trills in a call sequence. This is a call sequence that consisted of 5 calls: 3 chirps and 2 trills. In this case, Order of trills were 0.5 and 1.0.

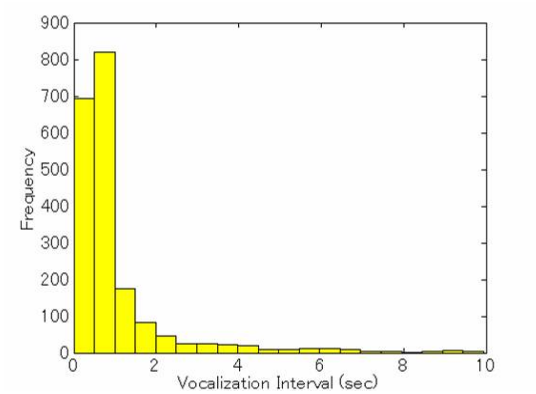

Fig. 5 The histogram of inter-call intervals of the dugong vocalizations.

the number of calls in the call sequence to be standardized. The standardized order of trill is described in the following equation (Eq.1):

The standardized order of trill = (i-1) / (N-1)   Eq.1.

Where i is call number of trill's and N is total counts of calls in a call sequences. If a trill was vocalized at the start of a call sequence, the standardized order of trill would be 0. If a trill was vocalized at the end of a call sequence, the standardized order of trill would be 1. For example, in this case, trill's phoneme number is 0.5 and 1.0 (Fig. 6).

RESULTS

We made observations of dugong calls. Table 1 shows the details from each of the four cases. Chirps were more frequent than trills in all cases. Chirp-chirp sequence was the most frequent in all cases. With respect to the dominant frequency, there were significant difference in all pairs except between individual-A and individual-B (Scheffe test $p < 0.01$).

Composition of call sequence

Figure 7 shows the percentage of the composition of each sequence. Blue area shows the percentage of the sequences that consisted of only chirps. Red shows the sequences with only trills, and yellow shows sequences that include both chirps and trills. The percentages of each sequence were almost the same between individual-A and individual-B. They were both from Philippines and have long been kept in Toba aquarium in Japan. In addition, chirp-to-chirp combination was the most frequent in all cases.

Table 1 Details of observed dugong calls

	Wild population <Thai>	Individual – A <Philippines>	Individual – B <Philippines>	Individual – C <Singapore>
Calls	2053	621	73	203
Chirps	1887	381	46	171
Call sequences & the average of calls in a sequences	335 avg. 5.79 ± 5.42 (SD)	119 avg. 2.97 ± 1.49 (SD)	20 avg. 2.45 ± 0.60 (SD)	43 avg. 3.7± 2.2 (SD)
The most frequent combination	C・C	C・C	C・C	C・C
The average of frequency (Hz)	4179.8 ± 1630.6	2538.5 ± 1218.1	2811.1 ± 634.6	7362.0 ± 1745.6

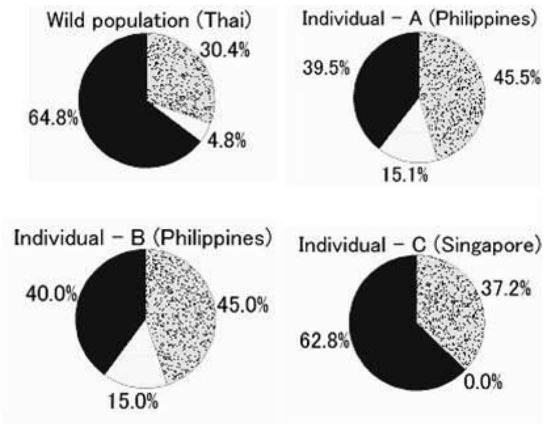

Fig. 7 Composition of call sequence. Solid area shows the percentage of the sequences that consisted of only chirps. Plain area shows the only trills, and dotted area shows sequences that include both chirps and trills.

State transition probability

The probability of transition between chirp and trill was calculated. Figure 8 shows the state transition of wild population, individual-A, individual-B, and individual-C. C shows chirps. T shows trills. The figure shows the number and the percentage of each transition. The number of chirp-to-chirp transitions is shown in the upper left box. The number of chirp-to-trill transitions is in the upper right box, trill-to-chirp transitions in the lower left box, and trill-to-trill transitions in lower right box. For example, in the individual-A figure, the transition of chirp to chirp occurred 118 times, being 50.42 % of all the transitions and chirp to trill transitions occurred 52 times, being 22.2 % of all the transitions. According to these figures, chirp to chirp transition was the most frequent in all cases. Vocalization transition showed similar patterns for the 4 groups, especially for individuals A and B. Transitions were significantly biased (chi-squared test, df = 3, $p < 0.01$ in all groups). Vocalization followed a specific pattern.

Structure of call sequence

The results of each group are show in Fig.9 as histograms of trill's position in a call sequence. In these figures the horizontal axes show standardized order of trills and the vertical axes the frequency of occurrence in percentage. According to these figures, trills frequently appeared at the end of a sequence.

DISCUSSION

We classified and analyzed dugong calls in the four cases to find statistical significance or transition probabilities. The methodologies used in these analyses were effective to study vocal structure of dugong calls. It was revealed that dugongs often vocalized short calls, or chirps. Dugong vocalization patterns were investigated. The most frequent combination was call sequences that were composed of 2 calls: chirp-chirp.

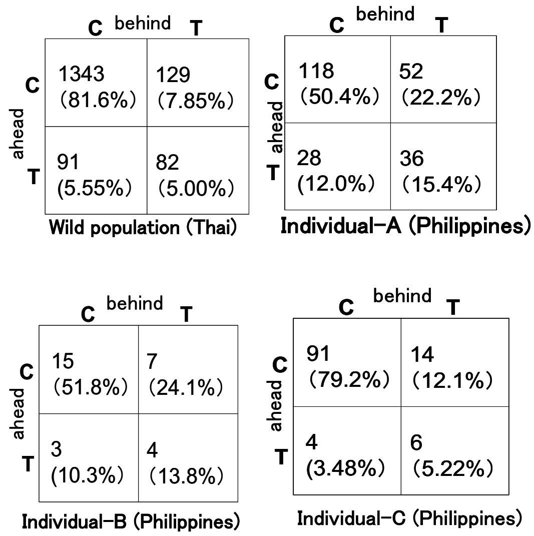

Fig. 8 State transition probability.

Transitions of dugong calls were significantly biased. The standardized order of trill in a call sequence stayed constant. Trills were often vocalized in the beginning or the end of a call sequence. Vocalization transitions showed similar patterns for the four groups, especially for Individual-A and Individual-B. Transitions were significantly biased (chi-squared test, df=3, $p<0.001$ in all groups). Thus, vocalization followed a specific pattern. These results suggested that dugong vocalization had a pattern with rules.

Composition of call sequence and state transition probability were similar in all cases. In addition, Individuals - A and B were especially similar. Call duration did not differ significantly between Individual-A and Individual-B. There was no significant difference in dominant frequency, either. These results suggested that the acoustical characteristics or vocalization patterns on dugong calls among Asian populations was almost the same. Unfortunately, this current study did not succeed in recognizing the individuality within the Thai population.

Statistical significance was found in the dominant frequency of the calls between the Thai population and Toba and UWS. The dominant frequency of the Thai population, Toba and UWS could have been the second harmonics, fundamental frequency and the third harmonics, respectively. Individuals A, B, C were brought to an aquarium when they were infants. Individuals A and B have heard only mutual calls. Individual C has not been influenced by the calls of other dugong calls after the separation from her mother. We can guess that the cause of this difference could be process of vocal learning, or environmental condition or growth stage.

This study provided detailed information on the vocalization pattern of the dugong, although the functional use of the calls in the context of acoustic communication is yet to be clarified.

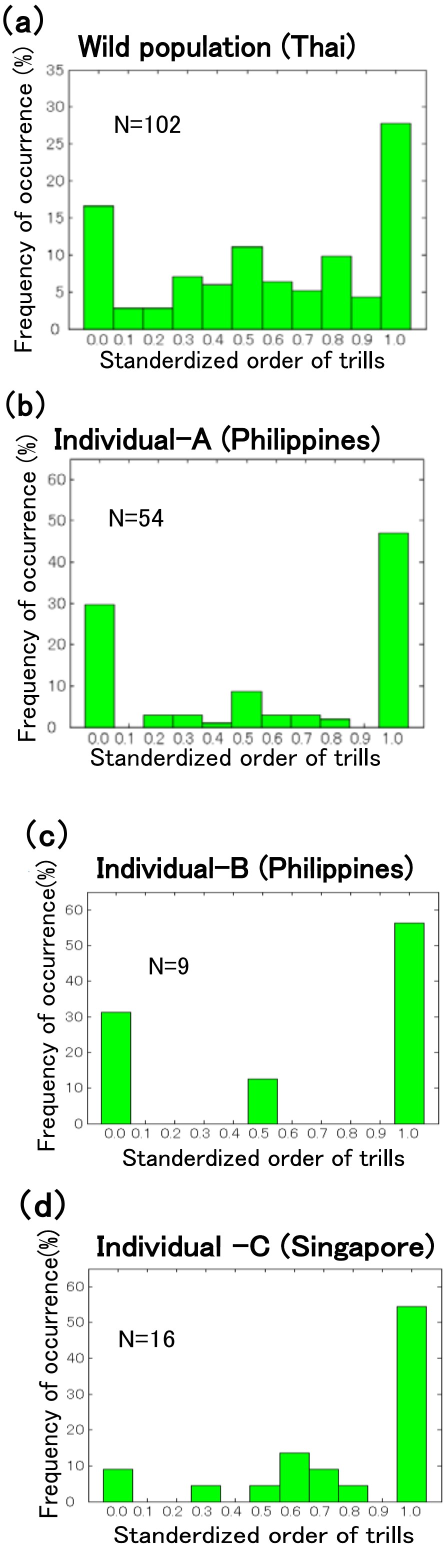

Fig. 9 Histograms of trill's position in a call sequence of wild population (a), individual-A (b), individual-B (c), and individual-C (d).

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REFERENCES

Anderson, P. K. and Barclay, R. M. A. (1995). Acoustic signals of solitary dugongs: physical characteristics and behavioral correlates

D'Vincent, C. G. et al. (1985). Vocalization and coordinated feeding behavior of the humpback whale in southeastern Alaska, *Sci. Rep, Whales Res. Inst*, 36, 41-47.

Ford, J. K. B. (1989). Acoustic behavior of resident killer whales (*Orcinus orca*) off Vancouver Island, British Columbia, *Can. J. Zool*., 67, pp. 727-745.

Ichikawa, K. et al. (2004-a). Acoustical analyses on the calls of dugong, *Proc. 4th Workshop on SEASTAR2000*, 72-76

Ichikawa, K. et al. (2004-b). Acoustical monitoring of dugong, *OTO '04 Abstract.*

Okanoya, K. (2003). Explore origin in the bird song, Iwanami, 84-104 (*in Japanese*).

Sugiura, H. et al. (, 1999). Sound transmission in the habitats of Japanese macaques and its effect on populational differences in coo calls, *J. acoustical acoust*. Society of. Japan, 55, 679-687 (*in Japanese*).